STATEMENT OF
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BEFORE THE
COMMITTEE ON SCIENCE, SPACE & TECHNOLOGY
SUBCOMMITTEE ON SPACE & AERONAUTICS

MAY 26, 2011

Mr. Chairman, Congressman Costello and the Members of the Space Subcommittee,

On behalf of Space Exploration Technologies (SpaceX) and our more than 1,300 employees across the United States, I thank you for the opportunity to participate in today's hearing.

With the imminent retirement of the Space Shuttle and the United States' forthcoming reliance on Russia to carry astronauts to the International Space Station (ISS), the readiness of commercial providers to support the ISS is a timely and critical topic. I am pleased to testify that, in partnership with NASA, SpaceX is on track to support the ISS, for cargo and eventually crew carriage.

To date, under the auspices of NASA's innovative and cost-effective Commercial Orbital Transportation Services (COTS) program, the SpaceX Falcon 9 launch vehicle and Dragon capsule have flown successfully and SpaceX has become the first-ever private commercial entity to successfully launch, orbit, reenter and recover a spacecraft. These achievements are unprecedented in terms of their scope, pace, and low level of expenditure. Let me repeat for emphasis here — what SpaceX achieved last year with the support and guidance from our NASA partner is nothing less than extraordinary. Indeed, in the history of space development efforts, we believe that the United States Government has never before received so much output and value relative to dollars spent. The COTS program serves as a model for public-private partnerships, focused on results-oriented, cost-effective, rapid prototyping, design and development.

All praise for COTS aside, there remains work to be done and challenges to overcome as the Nation looks to domestic commercial providers like SpaceX to support the ISS. I will begin my testimony by providing the Subcommittee with a brief overview of SpaceX and our operations. Next, I will address key achievements realized to date, then focus on remaining challenges in development, testing and demonstration. Finally, I will discuss where SpaceX stands with respect to the remaining COTS milestones with a focus on our upcoming mission to the ISS, technical and operational risk reduction efforts and contingency planning as we transition from COTS to our Commercial Resupply Services (CRS) missions.

SpaceX: Innovation Yielding Highly Reliable, Affordable Launch Services

Founded in 2002 by Elon Musk with the singular goal of providing highly reliable, cost-effective access to space to eventually facilitate carrying crew, SpaceX is headquartered in Hawthorne, California. The Company has developed a state-of-the art propulsion and structural testing facility in Texas and maintains offices in Huntsville, AL, Chantilly, VA, Washington, D.C., and shortly, Houston, TX. SpaceX has established launch sites at Cape Canaveral Florida, Vandenberg Air Force Base California, and the Kwajalein Atoll in the Marshall Islands.

Recently ranked as one of the world's fifty most innovative companies by MIT's *Technology Review*, SpaceX is governed by the philosophy that simplicity of design, reliability and affordability go hand-in-hand. We hard-wire that philosophy into our Falcon rockets and Dragon spacecraft by focusing on simple, proven designs, keeping a tight control over quality and ensuring a tight feedback loop between the design and manufacturing teams. To be clear, safety and reliability are paramount for any commercial company; and cost-reduction without safety and reliability is meaningless.

Our workforce, which has grown rapidly from two employees in 2002 to more than 1,300 employees today, embodies the best American ideals of hard work, ingenuity and excellence. Our particular emphasis on developing U.S. engineering and manufacturing capabilities has yielded SpaceX (and, by extension, the Nation) deep domestic, in-house expertise in propulsion, structures, avionics, safety, quality assurance, mission operations, launch, mission management and systems integration.

SpaceX's operational vehicles currently include the Falcon 1 and Falcon 9 launch vehicles and the Dragon spacecraft. Critically, SpaceX's Falcon 9/Dragon system offers an affordable, American-made, end-to-end transportation solution for carrying cargo and potentially crew to the ISS. With respect to development efforts, the Falcon Heavy launch vehicle development (which is not to be confused with NASA's heavy-lift development efforts) is underway, with an expected launch in 2013, and SpaceX is a recent recipient of a CCDev2 award focused on the development of an integrated launch abort system for the Dragon spacecraft.

SpaceX has executed at an unprecedented pace of development and success for an aerospace company, with nearly 40 Falcon 9 missions on manifest, approximately $3 billion in contracts and a customer base that spans the government, commercial and international markets in just nine years. As a result, SpaceX has been profitable every year since 2007, despite dramatic employee growth and major infrastructure and operations investments. Our ability to successfully compete in the domestic and international commercial market demonstrates the long-term viability of our business model and allows us to keep our costs to the U.S. taxpayer low.

To ensure that SpaceX is not dependent upon a single source for any key technology, we have developed the capability to manufacture the majority of our launch vehicle and spacecraft in-house. This provides us with control over quality, schedule and cost, for all key elements from component manufacturing through launch operations. It also allows SpaceX designers to work

directly with manufacturing personnel located just steps away, which streamlines the development process.

Total SpaceX expenditures from 2002 through 2010 were less than $800 million, inclusive of all Falcon 1, Falcon 9 and Dragon development costs. That $800 million includes the cost of building launch sites at Vandenberg, Cape Canaveral and Kwajalein, as well as the SpaceX corporate manufacturing facility. The total also includes the cost of five flights of Falcon 1, two flights of Falcon 9 and one launch and reentry of Dragon. It is fair to say that this level of output versus expenditure is unprecedented in the aerospace community.

Indeed, NASA recently conducted a predicted cost estimate of the Falcon 9 launch vehicle using the NASA-Air Force Cost Model (NAFCOM), its primary cost estimating tool. It was determined that had the Falcon 9 been developed under a traditional NASA approach, the cost would have been approximately $4 billion. The analysis also showed development of the Falcon 9 would have been approximately $1.7 billion based on the traditional commercial models and assumed factors. However, NASA independently verified SpaceX's total development costs of both the Falcon 1 and Falcon 9 at approximately $390 million in the aggregate ($300 million for Falcon 9; $90 million for Falcon 1).

COTS: Key Achievements to Date

The COTS program was the first of its kind for NASA: a "pay for performance" partnership between the government and private business to rapidly design and prototype critical technologies. NASA structured the COTS program as a collaborative partnership with the commercial space industry, sharing the risks, costs and rewards of developing new space transportation capabilities. Under the program, NASA provides seed money for the development of private spaceflight capabilities, but issues payment only after a company meets technical and financial performance milestones. The participating COTS contractors, likewise, invest in the program and put their own financial "skin in the game."

To date, SpaceX has completed 25 milestones under its COTS Agreement for efforts associated with the development, manufacture and testing demonstration of the Falcon 9 rocket and Dragon spacecraft for cargo carriage to the ISS. (The milestones completed under SpaceX's 2006 COTS Space Act Agreement, prior to amendment for augmentation milestones, are listed in Appendix A, attached.) Critically, SpaceX is well on its way to completing the integration process with the ISS. To date, NASA's Commercial Cargo program has contributed $298 million towards this end. And, in doing so, the United States also has helped facilitate the development of the first internationally competitive launch vehicle in more than a decade and the first-ever operational, private, orbiting and reentry capsule. In terms of "bang for the buck," the United States Government has made a savvy investment.

At present, SpaceX has performed two successful Falcon 9 flights. Each flight carried a Dragon spacecraft – the first mission carried an inert, non-separating Dragon, and the second carried an operational Dragon. The second Falcon 9 launch was the first official launch under the COTS program. It bears noting that the Falcon 9 launch vehicle features nine SpaceX Merlin engines in the first stage, which allows the Merlin engine to rapidly attain heritage by means of each flight.

The Merlin is the first new all-American hydrocarbon engine for an orbital booster to be flown in forty years and Falcon 9 is the first U.S. launch vehicle with engine-out capability after liftoff since Saturn V.

On December 8, 2010, SpaceX became the first commercial company in history to launch, reenter, and successfully recover a spacecraft from Earth orbit. SpaceX's COTS demonstration mission blasted off at 10:43 AM EST from Launch Complex 40 at Cape Canaveral. Falcon 9 lofted the Dragon to orbit where it twice circled the Earth at speeds greater than 7,600 meters per second (17,000 miles per hour). Dragon reentered the Earth's atmosphere and splashed down just after 2:00 PM EST in the Pacific Ocean. The mission was nothing short of a complete success.

Until late last year, launching, orbiting, reentering and recovering a spacecraft was a feat previously performed by only six nations or government agencies: the United States, Russia, China, Japan, India, and the European Space Agency. NASA's expert advice and mentorship throughout the development process helped SpaceX build upon 50 years of U.S. space achievements to reach this goal.

Once again, the financial facts are import to digest here: the Falcon 9 launch vehicle was developed from a blank sheet to first launch in four-and-a-half years for approximately $300 million. The Falcon 9 is an EELV-class vehicle that generates roughly one million pounds of thrust (four times the maximum thrust of a Boeing 747) and carries more payload to orbit than a Delta IV Medium. Likewise, the Dragon spacecraft was developed from a blank sheet to the first demonstration flight in just over four years for about $300 million. The Dragon is a free-flying, reusable spacecraft capable of delivering pressurized and unpressurized cargo to the ISS and safely returning cargo to Earth.

COTS Augmentation Milestones

At NASA's request, prior to Dragon's successful orbital flight, SpaceX began conducting additional tests on the launch vehicle and spacecraft and performed additional Dragon component system capability demonstrations. Those tests and demonstrations contribute to the eighteen new COTS milestones, known internally as "augmentation milestones," that have presently been added to our COTS Agreement. The uncertainty in Fiscal Year 2011 funding profiles led NASA to divide COTS funding among multiple amendments to its COTS agreements.

The COTS augmentation milestones exceed the tests and demonstrations originally agreed to by SpaceX and NASA for COTS when the parties first signed their Space Act Agreement. Specifically, certain milestones augment pre-planned ground and flight testing, and others accelerate the development of enhanced cargo capabilities with the remaining focusing on infrastructure improvements. The additional milestones further develop the ground infrastructure needed for cargo carriage operations and help improve the launch and recovery operations, test site and production facility infrastructure. In short, COTS augmentation milestones are meant to further reduce risk and enhance the execution of the cargo demonstration and operational missions to be performed under the COTS and CRS programs. The COTS

augmentation milestones that have been completed to date total $40 million. NASA recently added eleven augmentation milestones as an additional amendment to the COTS agreement. Those tests, reviews, demonstrations and infrastructure enhancements are planned to be completed prior to the next COTS mission. (The augmentation milestones and associated rationale for each are listed in Appendix B, attached.)

Fulfilling the COTS Objectives: Next Steps and Remaining Challenges

SpaceX's next flight of Falcon 9 with the Dragon spacecraft is scheduled to occur later this year. The final parameters of that flight are under discussion with NASA; however, SpaceX's goal is to have that COTS flight culminate in Dragon delivering cargo to the ISS and returning cargo safely to Earth. The mission will require SpaceX to accomplish all of the criteria for Demonstration Flight 2 prior to beginning the Demonstration Flight 3 criteria, which include berthing with the ISS. In effect, SpaceX will have fully achieved the development and demonstration goals of the COTS program and be prepared to undertake its CRS missions. Importantly, if SpaceX does not meet the mission success criteria for Demonstration Flight 2, then we would be prepared to fly once more under the COTS agreement if necessary. Here, it bears noting as a point of comparison that the European ATV and Japanese HTV conducted ISS operations on their maiden voyages. Orbital's current plan likewise calls for berthing on their first flight to the ISS.

A number of modifications have been made to Dragon to ensure a successful next flight and ISS berthing. To reduce the risk involved with Dragon approaching the ISS, redundancy has been added to the safety-critical systems. As an example, the initial mission flew one flight computer and one inertial measurement unit (IMU), while the ISS-missions fly multiple flight computers and IMU's to meet the ISS required fault tolerance.

To facilitate safe ISS berthing, the Dragon will be flying a proximity operations suite, including space-to-space communication systems and proximity navigation sensors. These are complex systems that present challenges. Additionally, Dragon will be flying a grapple fixture and a Passive Common Berthing Mechanism (PCBM), which are the physical attachment mechanisms for the ISS. As the next mission will be longer in duration than the first, a new power generation system, including solar arrays and new batteries, are in development. Star trackers and an active thermal control system have been added to sustain Dragon on orbit.

Ensuring Safe, Highly Reliable Access to Space

Given the purpose for our founding, SpaceX is first and foremost devoted to safety and reliability. By the nature of the business, commercial spaceflight providers cannot afford to take unnecessary risks that would endanger cargo or crew. As is true with respect to commercial aviation, businesses will fail unless safety and reliability come first, regardless of price. The need for a laser-like focus on safety and reliability becomes even more acute when commercial space companies have their own financial skin in the game, offer services on a firm, fixed price basis, and only get paid in full if they perform.

Per the Subcommittee's inquiry, SpaceX has plans in place to investigate, understand and take action, if necessary, for any anomaly that occurs during a mission. SpaceX has worked with the FAA, NASA, Air Force and National Transportation Safety Board in this respect. The time required to complete the process would, of course, depend on the actual nature of the situation being addressed.

SpaceX has demonstrated the capability to react rapidly in the event of test or flight anomalies. As an example, during the Falcon 1 flight 3, which was a demonstration mission of our smaller launch vehicle in mid-2008, a failure occurred in flight. SpaceX arrived at the root cause of the failure within a day, quickly implemented the fix, and less than seven weeks later, successfully launched Falcon 1 flight 4.

In the case of a COTS or CRS mission, SpaceX maintains an active Falcon 9 and Dragon production line. The subsequent Falcon 9 and Dragon spacecraft are always in production and able to be readied for launch quickly after making any modifications that might be indicated by an anomaly. Notably, due to our unique capabilities whereby we design, develop, build and test the majority of our hardware, we can achieve far faster turnaround on anomaly and failure investigations more quickly than anyone else in the industry. Instead of getting bogged down with an army of lawyers and subcontractors after a failure, our engineering and test team can rapidly determine root cause and resolution.

Commercial Resupply Services

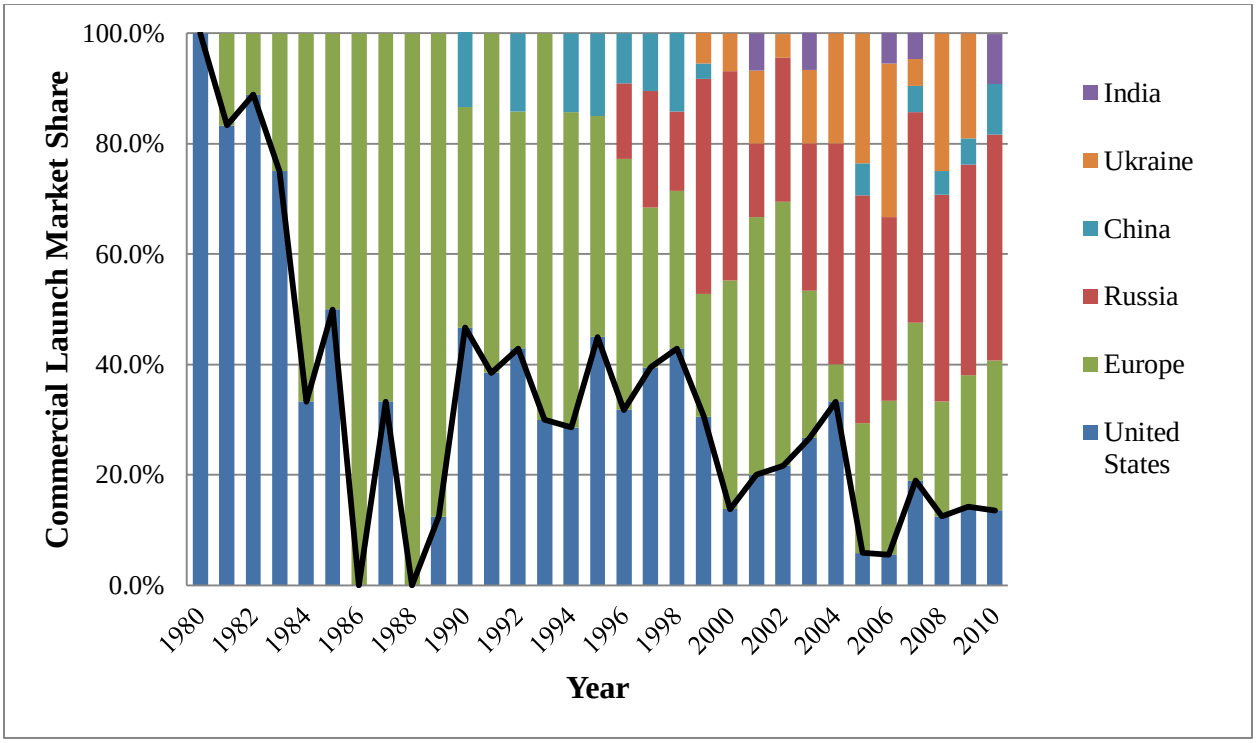
In 2008, SpaceX competed for and was awarded a Commercial Resupply Services (CRS) contract to deliver cargo to the ISS. Over the term of the CRS contract, SpaceX will deliver pressurized and unpressurized cargo to the ISS, including plants and animals, as well as return cargo to Earth. The $1.6 billion contract represents a minimum of 12 flights with an option to order additional missions.

It bears noting that the average price of a full-up NASA Dragon cargo mission to the International Space Station is $133 million including inflation, or roughly $115 million in today's dollars. That price includes the costs of the Falcon 9 launch, the Dragon spacecraft, all operations, maintenance and overhead and all of the work required to integrate with the ISS. Under SpaceX's firm, fixed price contract with NASA, if there are cost overruns, SpaceX will cover the difference, not the taxpayers.

SpaceX is preparing for an increase in the number of Falcon 9 and Dragon flights per year by expanding our production capabilities. Currently, SpaceX's near-term production capacity supports five to six Falcon 9 vehicles per year. The expansion plans will increase production capacity to produce ten to twelve Falcon 9 launch vehicles by 2013, and then twenty by 2015. This is roughly a 50% increase annually. In preparation for increased production, SpaceX has more than doubled the footprint of its structural and propulsion test facility in Texas. We have also reorganized the production teams into a more efficient, streamlined organization. SpaceX is working diligently to ensure that we successfully service our government and commercial customers.

Recapturing Commercial Launch Services Market Share

For the first time in more than three decades, an America company has begun to recapture international market-share in the commercial satellite launch sector – a sector in which the U.S. has seen steady erosion relative to Chinese, Russian and French competitors. SpaceX has begun successfully competing for and winning commercial satellite launch contracts. Whereas in 1980, 100 percent of commercial launches took place from within the United States; today, it is less than 12 percent.



Data compiled from FAA COMSTAC, launch services providers and space trade media.

Bringing back commercial launches to the United States is just one example of the benefits of NASA's targeted investment in SpaceX. By leveraging private funding with federal investment, controlling our costs and developing a diverse customer base, we are able to offer competitive pricing to our commercial and government customers. Likewise, safe, reliable and affordable transportation of cargo and astronauts to low Earth orbit by an American company will keep jobs in the United States, eliminate reliance on Russia to support the ISS, and save U.S. taxpayers significant money that instead can be invested in what NASA does best, pursuing the next frontier.

Mr. Chairman, thank you for your support and for the opportunity to participate in today's hearing. I would be pleased to respond to any questions you or the other Members of the Subcommittee may have.

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Appendix A:

Completed COTS Milestones (2006 Space Act Agreement baseline)

- ✓ Project Management Plan Review
- ✓ Demo 1 System Requirements Review
- ✓ Demo 1 Preliminary Design Review (PDR)
- ✓ Financing Round 1
- ✓ Demo 2 System Requirements Review
- ✓ Demo 1 System Critical Design Review
- ✓ Demo 3 System Requirements Review
- ✓ Demo 2 Preliminary Design Review
- ✓ Draco Initial Hot-Fire
- ✓ Financing Round 2
- ✓ Demo 3 Preliminary Design Review
- ✓ Multi-engine Test
- ✓ Demo 2/3 System Critical Design Review
- ✓ Financing 3
- ✓ Demo 1 Readiness Review (DRR)
- ✓ CUCU Flight Unit Design, Acceptance, and Delivery
- ✓ Demo 1 Mission
- ✓ Cargo Integration Demonstration

Appendix B:

Augmentation Milestones to COTS Space Act Agreement

Description	Purpose	Completed or Open	Amendment #
Pressurized Cargo Environment Modal Test Plan Setup and Pressurized Cargo Environment Modal Test	These two milestones provided early high fidelity data on the environments expected for Dragon cargo.	Completed	Amendment #5
LIDAR Sensors 6 Degree of Freedom Testing (open loop)	This milestone reduced the risk for the COTS flight to ISS by providing higher fidelity data to characterize the proximity sensor performance. The test was performed at the Marshall Space Flight Center Flight Robotics Laboratory whose capabilities allowed rapid testing for a large number of test scenarios. The data also helped to speed algorithm development.	Completed	Amendment #5
Solar Array Deployment & Component Thermal Vacuum Tests and Thermal Vacuum System Test Plan and Procurement	These two milestones included thermal vacuum testing of key Dragon and trunk subsystems to reduce risk on early flights to the ISS—with more cycles than would have been allowed in flight. An Aerospace Corporation study found that thermal vacuum tests uncovered an additional 43% of latent defects compared to only thermal cycle and unit testing.	Completed	Amendment #5
LIDAR Sensors 6 Degree of Freedom ("DOF") Testing Plan (closed loop)	This plan defines the detail of the 6 DOF tests that will provide true "test-like-you-fly" fidelity of the entire Dragon proximity Guidance, Navigation and Control (GNC) system. Also, by incorporating the sensors into the GNC bay of the Dragon drop test vehicle, near field obstructions will be introduced thus making this test the highest fidelity possible without approaching the actual ISS. Successfully flying the approach trajectory while discriminating the near field obstructions of the Dragon GNC Bay will greatly increase confidence that the software qualification testing, nominally done only via simulation, is adequate to fly the mission.	Completed	Amendment #6
Overall Infrastructure Plan and Long Lead Procurement	This milestone identifies high-value, high payoff modifications, upgrades and additional capabilities to the existing production, test and Launch Complex 40 facilities that will enhance and streamline cargo and	Completed	Amendment #6

	vehicle flows to benefit NASA's ongoing and long-term cargo transportation needs.		
Thermal Vacuum Tests (System Level)	Full up Thermal vacuum testing of the Dragon spacecraft and trunk system. This test reduces risk on all flights to ISS as simulated environments are generally wider than those experienced on orbit. This testing provides much confidence in component behavior in vacuum. This additional system level test will reduce the risk of anomalies on-orbit that could cause program delays.	Open	Amendment #7
Test Site Infrastructure Implementation, Launch Site Infrastructure Implementation and Production Infrastructure Implementation	To meet the criteria for these milestones, SpaceX will implement enhancements developed under a prior milestone, including high-value modifications, upgrades and capability additions to SpaceX's testing facility, Launch Complex 40 and production infrastructure. Improvements to the test facilities in McGregor, TX, will improve engine acceptance rates and structural testing times. The launch complex and production enhancements will improve and streamline cargo and vehicle production flows to benefit NASA's ongoing and long-term cargo transportation needs.	Open	Amendment #7
Dragon Trunk Acoustic Test	The acoustic test will provide systems-level workmanship verification for the Dragon solar array assemblies and integrated trunk assembly, by exposing it to the acoustic and vibration environment prior to actual flight. Extensive component testing is already done—this test represents a robust system level verification.	Open	Amendment #7
LIDAR Sensors 6 Degree of Freedom Test (closed loop)	This 6 DOF test which will provide true "test-like-you-fly" fidelity of the entire Dragon proximity Guidance, Navigation and Control (GNC) system. Also, with the sensors located in the GNC bay of the Dragon drop test vehicle, near field obstructions will be introduced thus making this test the highest fidelity possible without approaching the actual ISS.	Open	Amendment #7
Design Review of Enhanced Powered Cargo Accommodations and Demonstration of Enhanced Powered Cargo (ground)	In addition to various Life Science samples from NASA, which are currently accommodated in the Dragon capsule, there are numerous other now-funded science activities that will take advantage of powered mid-deck storage locations. This milestone will	Open	Amendment #7

	provide NASA design options to increase power, data and critical operations for a critical cargo capability		
Design Review of Pressurized Cargo Volume Increase	The cargo manifest with the COTS baseline Dragon is volume-limited on ISS flights, which results in excess mass capability on all missions. This design effort which culminates in a review will analyze high-value modifications to the Dragon to increase the cargo capacity beyond that proposed for COTS, possibly resulting in lower recurring cost (and cost per kilogram) for NASA. It is critically important to maintain the viability of the powered cargo locations and the early and late access capability.	Open	Amendment #7
Full Dragon EMI/EMC Test, Second Flight-Like HITL (Dragon Force)	A full-scale EMI/EMC test is final verification that the vehicle's electrical components will not interfere with either each other or external electrical components such as the ISS. This test will verify both radiated emissions and susceptibility. SpaceX will also develop another complete Hardware in the loop simulator called Dragon Force to ensure that multiple hardware and software test scenarios can run in parallel.	Open	Amendment #7
Dragon Cargo Racks and Hatch Simulator	This simulator will be developed and delivered to NASA to train crew and other flight team members in the cargo handling processes and procedures. In addition to training, the capability allows for the development of new cargo handling concepts and process improvement as well as the ability to develop crew aids as required.	Open	Amendment #7